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# Prediction of liquefaction potential study at Bantul Regency the province of special region of Yogyakarta Indonesia

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**Abstract**

The research was conducted to predict the potential liquefaction that may happen on some areas in Bantul regency the province of Special Region of Yogyakarta. To verify soil profile and N-SPT values, soil exploration was done on 4(four) selected locations in Bantul regency. The field exploration was then followed by some laboratory experiments in regard to physical and mechanical properties of soil. The results of soil exploration indicates that soil deposit is sand from the ground surface up to the depth of 30,00 meter, low to medium N-SPT values ( 15 < N <30), and high elevation of ground water level ( -5.00 to -9.00). Laboratory tests show that the soil is uniform poorly graded sand with Cu < 3, and Cc < 2, and relatively low internal friction angle in between 24° and 31°. The soil data, then analysed by means of the method developed by National Centre of Earthquake Engineering Research (NCEER). Analysis of potential liquefaction for 4 selected locations, during low accelerated earthquake ($a_{max}/g = 0.05$) there were no liquefaction zone. However, during Yogya earthquake 2006 ($a_{max}/g = 0.09$) there were liquefaction zone in between 17.00 to 19.00 that was very short and in the depth far below ground level. And at $a_{max}/g = 0.15$ there were long liquefaction zone from 4.00 to 30.00 meter below ground surface.


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*Keywords*: Cu ;Cc ;N-SPT; liquefaction

## 1. Introduction

Sand deposits, which are inherently low in cohesion and high in friction angle, are widespread in the Province of Special Region of Yogyakarta, Indonesia. When saturated, sand deposits are potentially liquefiable. Previous studies [1,2] indicated that sand deposit in Yogyakarta is uniform, and low to medium N-SPT values up to the depth of 60.00

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meters. Ground water level is very high, -4.00 meter, during rainy season. It was found, furthermore, that liquefaction potentially happened on saturated - uniform sand, diameter in between 2.00 mm to 4.00 mm ; low relative density , low N-SPT values [3]. In the province of special region of Yogyakarta, therefore, liquefaction is possible to happen during earthquake. Studies about liquefaction, especially evaluation studies, were progressively developed. Empirical models to predict horizontal displacement due to liquefaction was derived [4,5]. The use of energy concept to define soil liquefaction by means of laboratory experiment of sand was developed [6,7]. General approach to evaluate un drained stress-strain curves from tri axial experiment was formulated [8]. A relatively new probabilistic-empirical approach to evaluate liquefaction resistance based on Standard Penetration Test was proposed [9,10]. The most widely used method to evaluate liquefaction potential, however, is that developed by the NCEER workshop, 1998[11,12]. The method is basically the generation of simplified method developed by [3].

This study was proposed to evaluate the potential liquefaction that may happen in Bantul Regency the Province of Special Region of Yogyakarta, Indonesia. Soil exploration to provide data analysis were done on four selected locations in Bantul Regency.

## 2. Research Method

### *2.1. Soil Exploration*

Soil exploration was done on four selected locations, those are Information Technology Service Building that represent the west area of Bantul, The ISI campus representing the north area, The campus of Mercu Buana University that represents mid area and the office of Bantul Regent representing the south area of Bantul Regency. The locations then were respectively named as location (1), (2), (3), and (4). The scope of explorations are boring-log of 30.00 meters for each location to verify the soil profile, and Standard Penetration Test (SPT). The equipment was bore-machine Rotary Spindle Type: Skid Mounted with bore-hole diameter 7.295 cm. The equipment is capable to explore the soil up to the depth of 60.00 meters.

### *2.2. Soil Investigation*

Experiment to investigate Physical and mechanical properties were conducted in the Soil Mechanics laboratory of Engineering Faculty Atma Jaya Yogyakarta University. The investigation of soil moisture content (ASTM 2216-92, or SNI 1965 2008), Sieve Analysis (ASTM D 422 or SNI 3423: 2008), Specific gravity (ASTM D 854 or SNI 1964: 2008) were performed to determine physical properties of soil. To determine mechanical properties and stress- strain behavior was conducted on direct shear test (ASTM D 3080 or SNI 2813: 2008).

### *2.3. Selected Model and Procedure Analysis*

Selected model analysis in this study is the simplified method proposed by [11] that was developed by workshop performed three times at the year of 1996, 1998 and 2003 by the National Center of Earthquake Engineering Research (NCEER). The Cyclic Resistance Ratio (CRR) were specifically examined in the workshops that were guided by Youd and Idriss. The three workshops generated basically the previous methods proposed by [3,13] and the others researchers. The results of the workshops were published on [11], the analysis procedure is described as follow.

After the field soil data (soil profile, and N-SPT values), and laboratory soil data (moisture content, specific gravity, unit weight, sieve analysis, shear strength parameters) were obtained; the Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR) can be calculated. To calculate CSR is required the total and effective stresses up to the proposed depth to be investigated. In addition, peak ground acceleration ($a_{max}$) and depth reduction coefficient ($r_d$) are also required. To calculate CRR is then required normalized N-SPT values, magnitude scaling factor (MSF). After CSR and CRR were calculated, safety factor were evaluated. If safety factor is less than 1, liquefaction would not happen on the zone of proposed depth. Otherwise, if safety factor is larger than 1

## 3. Result and Analysis

### *3.1. Result of Soil Exploration*

The results of soil exploration on four selected location are summarized on Table 1. Figure 1 represents the results of bore-log on

Table 1. Result of Soil Exploration

| Depth | *Location 1* | | *Location 2* | | *Location 3* | | *Location 4* | |
|---|---|---|---|---|---|---|---|---|
| Elevation(m) | Soil Profile | N-SPT | Soil Profile | N-SPT | Soil Profile | N-SPT | Soil Profile | N-SPT |
| 0.00 to -2.00 | Fine sand | 0 to 30 | Fine sand | 0 to 31 | Fine sand | 0 to 30 | Fine sand | 0 to 20 |
| -2.00 to -4.00 | Rough sand | 30 to 28 | Rough sand | 31 to 27 | Rough sand | 30 to 35 | Rough sand | 20 to 35 |
| -4.00 to -7.00 | Medium sand | 28 to 23 | Med sand | 27 to 29 | Medium sand | 35 to 38 | Medium sand | 35 to 25 |
| -7.00 to -9.00 | Rough sand | 23 to 26 | Pasir kasar | 29 to18 | Rough sand | 38 to 35 | Fine sand | 25 to 32 |
| -9.00 to -11.00 | Silty Sand | 26 to 29 | Fine sand | 18 to37 | Medium sand | 35 to 32 | Medium sand | 32 to 24 |
| -11.00 to -13.00 | Medium sand | 29 to 27 | Rough sand | 27 to23 | Fine sand | 32 to 38 | Fine sand | 24 to 28 |
| -13.00 to -16.00 | Rough sand | 28 to 20 | Fine sand | 23 to 37 | Silty Sand | 38 to 24 | Fine sand | 28 to 18 |
| -16.00 to -22.00 | Fine sand | 20 to 28 | Med sand | 37 to 23 | Fine sand | 24 to 26 | Fine sand | 18 to 20 |
| -22.00 to -26.00 | Medium sand | 28 to 19 | Fine sand | 23 to 24 | Medium sand | 26 to 32 | Silty Sand | 20 to25 |
| -26.00 to -30.00 | Fine sand | 19 to 24 | Med sand | 24 to 26 | Medium sand | 26 to 40 | Fine sand | 25 to. 30 |
| Ground Water table | *-7.00* | | *-5.00* | | *-6.00* | | *-4.00* | |

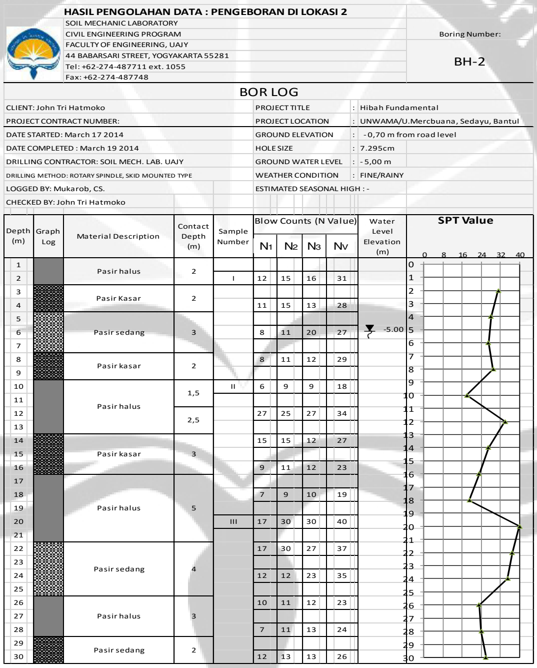


Figure 1. Result of Bore-Log on Location 2

Location 2 as a representation of the four selected locations.

The results of soil exploration on location 1 show that soil profile is fine to rough sand with SPT-N values low to medium ( $15<N<30$). Ground water table is on -7.00 Only on the elevation -9.00 to -11.00, there is silty-sand layer. Ground water elevation is on -7.00, and N-SPT values are in the medium stage in between 20 to 26. Similarly, on location 2, the soil deposit is dominated by fine to rough sand with medium N-SPT values around 18 to 31. Ground water table is on -5.00. Like on location 2, soil deposit on location 3 and 4 are mostly sand with medium N- SPT values. Therefore, it is possible that during earthquake liquefaction will happen on those selected locations. However, laboratory experiment should be performed to verify physical and mechanical properties of soil to make sure that liquefaction really happen to the investigated locations.

### 3.2. Laboratory Results

Soil samples were taken above and below groundwater level for each location. The result of sieve analysis is presented on Table 2.

Table 2. The result of sieve analysis

| *Location* | *Elevation(m)* | *$D_{10}$ (mm)* | *$D_{30}$ (mm)* | *$D_{60}$ (mm)* | *Cu* | *Cc* |
|---|---|---|---|---|---|---|
| 1 | 2.00 | 0.55 | 1.0 | 1.50 | 2.73 | 1.21 |
| | 10.00 | 1.60 | 2.70 | 4.00 | 2.50 | 1.14 |
| | 20.00 | 0.85 | 1.20 | 1.50 | 1.76 | 1.13 |
| **2** | 2.00 | 0.60 | 1.10 | 1.60 | 2.67 | 1.26 |
| | 10.00 | 1.00 | 1.50 | 2.50 | 2.50 | 0.90 |
| | 20.00 | 0.65 | 0.80 | 1.50 | 2.31 | 0.66 |
| **3** | -- | -- | -- | -- | -- | -- |
| | 9.50 | 0.85 | 1.50 | 2.40 | 2.82 | 1.11 |
| | 20.50 | 0.475 | 0.60 | 0.85 | 1.79 | 0.89 |
| **4** | 2.00 | 0.95 | 1.50 | 2.70 | 2.93 | 1.37 |
| | 10.00 | 0.85 | 1.70 | 1.80 | 2.11 | 1.89 |
| | 20.00 | 0.85 | 1.20 | 1.50 | 1.77 | 1.13 |

The laboratory data indicates that the soil is uniform poorly graded sand. Coefficient of uniformity is in between 1.76 and 2.5, and coefficient of curvature $C_C$ in between 1.13 and 1.21. Friction angle obtained from direct shear test was relatively low in between 25.73 and 26.89$^O$. Even though some of those are in between 1 and 3, the coefficient of uniformity ($C_u$) of soil on four selected location are less than 3 (1.77 < Cu < 2.93). The soil deposit, then can be classified as poorly graded sand that is potentially liquefiable.

Results of direct shear test is summarized on Table 3. The values of cohesion (c) are very low ( 0.038 < c < 0.083) kg/cm$^2$. Whereas the values of internal friction angles are relatively high in between 25.73 to 29.22$^O$. However, those values are small for sand. This is in line with the results of sieve analysis that uniform poorly graded sand has relatively low in friction angle.

Table 3. Summary of Direct Shear Test Result

| *Location* | *Elevation (m)* | *Cohesion, c (kg/cm$^2$)* | *Internal friction angle, Phi ($^O$)* |
|---|---|---|---|
| **1** | -2,00 | 0,083 | 25,73 |
| | -10,00 | 0,075 | 26,07 |
| | -20,00 | 0,068 | 26,89 |
| **2** | -1,50 | 0,067 | 25,98 |
| | -9,50 | 0,059 | 26,83 |
| | -20,50 | 0,065 | 26,23 |
| **3** | -2,00 | 0,043 | 27,76 |
| | -20,00 | 0,038 | 29,22 |
| **4** | -2,00 | 0,054 | 27,08 |
| | -10,00 | 0,048 | 27,56 |
| | -20,00 | 0,045 | 28,05 |

The values of internal friction angle (Phi) can be correlated to the N-SPT values by means of the equation Phi = $(12N)^{0.5} + 10$ [14]. The result of correlation indicates that there are close relation between correlated N-SPT and the field N-SPT values.

### 3.3. Liquefaction

Analysis of cyclic Stress Ratio (*CSR*) used simplified equation developed by[3] . Earthquake used the previous data published by Geophysics and Meteorology Directorate. According to the published data, the Province of Special Region of Yogyakarta experienced five big earthquake with magnitude is larger than 6.5. On September 10 1926 : M = 7.2; R = 51.91 km; on June 24 1958 : M = 6.5, R = 133.54 km; on November 8 1974 : M = 7.0; R = 54.30 km ; May 15 1979 : M = 6.8, R = 43.04 km; and on May 27 2006 : M = 6.0, R = 37 km. Based on the earthquake data then calculated peak ground acceleration ( $a_{max}$ ) are : 139.4, 29.45, 113.28, 120.05, and 86.872 cm/s$^2$. Whereas analysis of Cyclic Resistance Ratio (CRR) used the N-SPT values data. N-SPT values then be normalized by some factors. The correction factors are : hammer energy ($C_E$), bore- hole ($C_B$), rod length ($C_R$), and sampling method ($C_S$), by means of the equation : $(N_1)_{60} = N_m.C_N.C_E.C_B.C_R.C_S$. Then by using the method developed by NCEER workshop, CRR can be evaluated. Table 4 presents of the analysis of liquefaction.

Table 4. Result of Liquefaction Analysis

| *Elevation* | *CSR for ( $a_{max}/g$)* | | | | *CRR for Location* | | | |
|---|---|---|---|---|---|---|---|---|
| *(m)* | 0.09 | 0.15 | 0.20 | 0.25 | *(1)* | *(2)* | *(3)* | *(4)* |
| 0 | 0.0585 | 0.0975 | 0.13 | 0.1625 | 0 | 0 | 0 | 0 |
| 2 | 0.057611 | 0.096018 | 0.128024 | 0.16003 | 0.512621 | 0.520446 | 0.520446 | 0.280511 |
| 4 | 0.056722 | 0.094536 | 0.126048 | 0.15756 | 0.589218 | 0.643223 | 0.154424 | 0.159189 |
| 6 | 0.055832 | 0.093054 | 0.124072 | 0.15509 | 0.172431 | 0.199901 | 0.524125 | 0.229038 |
| 8 | 0.062737 | 0.104561 | 0.139415 | 0.174268 | 0.15033 | 0.184852 | 0.192102 | 0.127763 |
| 10 | 0.067461 | 0.112436 | 0.149914 | 0.187393 | 0.135839 | 0.094025 | 0.157844 | 0.107926 |
| 12 | 0.06644 | 0.110734 | 0.147645 | 0.184557 | 0.127004 | 0.159638 | 0.185414 | 0.141216 |
| 14 | 0.06537 | 0.10895 | 0.145266 | 0.181583 | 0.103767 | 0.111443 | 0.126106 | 0.0975 |
| 16 | 0.063362 | 0.105603 | 0.140803 | 0.176004 | 0.074185 | 0.083267 | 0.117052 | 0.077522 |
| 18 | 0.060651 | 0.101085 | 0.13478 | 0.168475 | 0.054145 | 0.064262 | 0.103464 | 0.087468 |
| 20 | 0.057405 | 0.095675 | 0.127566 | 0.159458 | 0.07103 | 0.106715 | 0.092114 | 0.058033 |
| 22 | 0.053738 | 0.089563 | 0.119417 | 0.149272 | 0.065976 | 0.090841 | 0.095125 | 0.0487 |
| 24 | 0.04973 | 0.082884 | 0.110512 | 0.13814 | 0.053526 | 0.077146 | 0.058989 | 0.050276 |
| 26 | 0.045446 | 0.075744 | 0.100992 | 0.12624 | 0.045496 | 0.052045 | 0.056923 | 0.06034 |
| 28 | 0.040935 | 0.068224 | 0.090966 | 0.113707 | 0.047416 | 0.050517 | 0.056535 | 0.059724 |
| 30 | 0.036233 | 0.060388 | 0.080518 | 0.100647 | 0.054521 | 0.050473 | 0.085326 | 0.059052 |

At $a_{max}/g$ 0.09 there is a short liquefaction zone on the elevation of : 17.00 to 19.00 due to the small N-SPT value of the zone, N = 15 at 18.00. The zone of liquefaction is short and on the depth far below the ground surface. The larger the value of $a_{max}/g$, the longer the liquefaction zone. For example, at $a_{max}/g = 0.15$, there will be liquefaction zone from 14.00 to 30.00. Similar to location 1, soil exploration on location 2 indicate that soil profile is fine to rough sand, no fine material. N-SPT values , however, is relatively high 32 to 40. At the elevation of 10.00 to 18.00, it was found low N-SPT value around 17. Sieve analysis results on some elevation on this location indicate that soil profile is mostly uniform poorly graded sand. Coefficient of uniformity is relatively low between 2.31 and 2.67 and coefficient of curvature is 0.66 to 1.26. Direct shear experiment resulted on low friction angles. Evaluation of liquefaction indicate that there is no liquefaction zone at $a_{max}/g = 0.09$. However at $a_{max}/g = 0.15$ there will be liquefaction zones at -9.50 to -11.00 and -14.00 to -19.00.

Like on location 1 and 2, soil profile on location 3 and 4 is dominated by fine to rough sand. On location 3, there is silty-sand layer on the elevation -21.00 to -23.00. Ground water level at -9.00. N-SPT values are relatively high more than 30 for every layer. Result of sieve analysis show that soil on location 3 is uniform poorly graded sand with coefficient of uniformity less than 2.8, and coefficient of curvature is less than 1.11. Internal friction angle obtained from direct shear test is relatively low, that is less than 27.75$^{\circ}$. Liquefaction zone is going to happen when $a_{max}/g$ = 0.15. The zone is from -23.00 to -29.00. Similar to on location 3, soil deposit on location 4 is fine to rough sand that is uniform poorly graded. N-SPT values, however, is lower compared to those of on location 3. During medium to high earthquake acceleration, there are long liquefaction zone on location 4.

## 4. Conclusion

Analysis of potential liquefaction on four selected locations in Bantul Regency was done, the following are conclusion of the study. At location 1, there is no liquefaction zone when amax/g = 0.05, When amax/g = 0.09 there is liquefaction zone on -17.00 to -19.00 that is very short and far below the ground surface. For amax/g = 0.15 there is long liquefaction zone from -14.00 to -30.00. The liquefaction zone is longer when amax/g = 0.20. Similar to on location 1, liquefaction zone on location 2 is very small when amax/g = 0.05 and 0.09. At amax/g = 0.15, liquefaction zone appear on -9.50 to -11.00, and -14.00 to -19.00. On location 3 and 4, liquefaction zones appear when amax/g = 0.15, there are -23.00 to -29.00 an location 3 and -20.00 to -24.00 on location 4.

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